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THE BELL SYSTEM TECHNICAL JOURNAL

DEVOTED TO THE SCIENTIFIC AND ENGINEERING ASPECTS OF ELECTRICAL COMMUNICATION

Volume 61 | March 1982 | Number 3

Video Colorization Diagnostics in Optical Telecommunications

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(Manuscript received October, 1981)

A new diagnostic tool is used to study the outputs of light-emitting diodes, lasers, and optical fibers, and to provide quality control of optical fiber preforms. The object is observed with a video camera, and the monochrome signal is processed to synthesize a color display from the different intensity levels. The color representation allows features not previously observable to be readily recognized and characterized. Correlation between separated, but equally bright, regions of a video image is also easily achieved in that they are now rendered in the same color. A calibration procedure allowing quantitative information to be quickly obtained from the display is described.

I. INTRODUCTION

Video diagnostics is capable of playing an important role in the study and characterization of the components used in optical telecommunications. The term itself refers to obtaining information from a video signal derived by viewing the object, or a property of the object of interest, with a video camera. Prime examples are observing the light output of light-emitting diodes (LEDs) or of fibers. The video image will then consist of a two-dimensional display of the intensity at the plane upon which the camera is focussed. For LEDs, this plane could correspond to the output face of the device so that the near-field

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radiation pattern can be characterized and, in the case of fibers, it could be a screen upon which the fiber output is allowed to fall.

The display contains a very large amount of information in the form of point-to-point variations in intensity. This information could of course be computer-processed to yield the desired data and, indeed, a host of such systems exist in both specialized[1,2] and commercially available form.

However, in many applications, this sophistication and associated expense is not required as the desired information could be obtained by simply observing the monitor display if some means existed of distinguishing the various intensity levels. Unfortunately, it is difficult for the monochrome monitor screen and the eye to discern small changes in grey scale and to correlate them over an extended two-dimensional image. On the other hand, the human visual system is very sensitive to small color changes, which can then be used as a means of image enhancement.

This paper describes a method based on the latter effect to achieve distinction and subsequent correlation in a video image by converting different shades of grey into synthetic color signals. We apply the term video colorization to this procedure in analogy with video digitization, since the signal is represented by a discrete number of synthetic colors. By just observing the color display, all of the required information for many applications can then be obtained. Examples are given of studies of LED, laser, and fiber output light distributions and also of the internal structure of optical fiber preforms.

II. VIDEO COLORIZATION

The advantages of converting monochrome displays into color is receiving considerable attention[3] and is making a major impact in computer graphics.[4] Not only does color separate and highlight information better but it also serves to direct attention to particular areas of interest. This latter point has been found to improve operator recognition and lower probability of operator error in situations where judgments are based on monitor displays. In addition to its laboratory research value, the system to be described here is well-suited to a manufacturing environment for use by personnel in product testing and quality control.

Video colorization diagnostics is achieved with the arrangement shown in Fig. 1. A video camera observes the object or intensity distribution of interest either with a camera lens, through a microscope or by projecting directly onto the face of the vidicon itself. The vidicon is a silicon target type adjusted for linearity and uniformity of response.

The output of the camera is sent to a video quantizer.[5] This instru-

ment is specifically designed to process the grey-scale characteristics of a monochrome video input signal to synthesize color signals from different shades of grey. It achieves this by dividing the input signal into a maximum of eight slices and assigning a color to each slice. The width of the slices is adjustable to any amplitude level between black and white, and the color assigned to each slice can be any combination of red, blue, and green.

The video quantizer generates a test pattern on the red-green-blue color monitor to facilitate the above adjustments. Three such patterns which appear as vertical bands of color are shown in Fig. 2. The width of each band corresponds to a voltage range in the video signal. Optimal resolution is obtained if the total width of the bands is equal to the total voltage range of the input signal.

Figure 2a shows the condition in which each band has an equal width and the intensity progression goes from black to white with the colors in the order, black, red, yellow, green, light blue, dark blue, violet, and white. Thus, the darker parts of the image will be rendered black and red and the brighter segments in white and violet, with the other colors falling in between.

Figure 2b shows the test pattern setup for a logarithmic response and Fig. 2a, for equal brightness contour generation. In the latter case, as will be shown later, the image on the monitor is composed of a series of equal brightness contours.

The logarithmic response is of particular value in calibrating the conversion of grey scale into color. Figure 3a shows the monochrome display of a neutral-density step wedge as observed by the video camera. Eight steps are included in the field of view varying in density from 0.22 to 1.36, giving a range of relative brightness from 100 to 7 percent. Note that only four of the steps are clearly resolved. With the test pattern set for a logarithmic response to match the density steps of the wedge, Fig. 3b is observed. Note that now all eight steps are seen and that a particular color can be associated with a given grey-scale value. We now present the results of applying this system to a variety of objects.

III. OPTICAL FIBER OUTPUT

The output radiation pattern of a multimode optical fiber consists of a complex configuration determined by the mutual interference effects of the propagating modes. A typical pattern observed for laser excitation of the fiber is shown in monochrome form in Fig. 4a. The main feature noted is patches of light of varying intensity. Generally, from a systems perspective it is only the total power in this distribution which is of interest; however, recent attention being paid to modal noise makes details of the pattern important.[6] The intensity distribu-

tion is also of interest in characterizing the fiber or mode distributions themselves, and properties of it can be used in multimode fiber interferometry.

Characterizing the light output distribution or focusing attention upon a specific feature of it is made possible with video colorization. A colorized intensity pattern is shown in Fig. 4b. Regions of equal intensity are now clearly delineated and the brightest patches of light stand out in white. For comparison, an equal brightness contour display of the pattern is shown in Fig. 4c.

The output light distribution is extremely unstable to small perturbations of the fiber. Touching the fiber at any point along its length dramatically changes the observed pattern. Even air currents are sufficient to perturb the distribution as displayed in Fig. 5, which shows the output as observed over a several-minute time interval under normal ambient room conditions. If the total power of this distribution is not detected (as may occur with certain fixed apertures or splices in a fiber system), these variations become an important source of modal noise and video colorization offers a way to study the effects. Video colorization also opens up other possibilities in that now a specific feature of the pattern can be easily monitored and its changes as a function of external stimuli recorded. This allows multimode fibers to be used in sensitive interferometric-like detection schemes to monitor quantities like, pressure, temperature, or even electric and magnetic fields.[7]

IV. LIGHT-EMITTING DIODES AND LASERS

Video colorization is ideally suited to characterize the light outputs of LED and laser sources. The output consists of a two-dimensional intensity distribution which can be immediately analyzed once it is colorized. The LED devices are observed with a microscope focussed on their emitting surface to obtain the near-field light distribution.

Figure 6 shows a poor quality LED observed in black and white and in colorized form. The most intense emission regions are clearly seen in the colorized photos which show the output of the device as a function of increasing current.

An LED with a relatively uniform output light distribution is shown in Fig. 7. Note that the colorized display shows some nonuniformity in the contact region (near the upper left) and a small bright area in violet just to the left of center.

Two views of the output of a GaAlAs laser are shown in Fig. 8. Figures 8a and 8b show the near-field pattern, and Figs. 8c and 8d show the far-field pattern; the latter is obtained by focussing on a ground glass upon which the radiation impinged.

V. PREFORM STRUCTURE

As is well known, the quality of the refractive index profile of an optical fiber determines, in the absence of mode coupling, the bandwidth of the medium. In the modified chemical vapor deposition (MCVD) process, the profile is built up in a layered fashion by varying the dopant concentration in the deposited layers. Layer structure, then, is an important indicator of profile quality and techniques have been developed to render it visible for inspection in the preform state.[8]

One way of investigating the layer structure is by immersing the preform in matching oil and observing the core with a video camera.[9] A preform observed in this manner is shown in Fig. 9a. The central dark band outlined with two bright lines is the axial index depression. The two bright lines further out arise from a deposition layer with an index much higher than that of the adjacent layers and represent a deposition flaw. While this perturbation is visible in the monochrome display, its presence can be enhanced by video colorization as shown in Fig. 9b. In this display, the test pattern was set so that all grey levels below a certain value would be rendered in red. Grey levels above this threshold, representing deposition flaws, are rendered in yellow. Thus, a difinitive indicator is provided to check preform quality.

Similar observations on a single-mode preform are shown in Fig. 10. Figure 10a shows in monochrome the GeO_2-doped core in the lower region and the phosphosilicate layers above it which make up the deposited cladding. Figure 10b is a colorized display with the test pattern set to show up the uniform deposition structure in the cladding. For Fig. 10c, the test pattern was adjusted to best show uniformity of the core deposition.

Video colorization is also an aid in viewing the layer structure as observed in preform slab samples. Figure 11 shows such a sample and how colorization helps in making visible the fine details within the layers.

As a last example, consider Fig. 12 which demonstrates a use of general utility. The monochromatic display in Fig. 12a comes from viewing the output of a collimated tungsten-halogen light source intended to supply a uniform intensity distribution. How well this uniformity is achieved is clearly seen in the colorized display of Fig. 12b. We, thus, have a very sensitive procedure to test background or incident light distributions for uniformity.

In conclusion, we have seen that video colorization can be used as a tool that can enhance and, in some cases, even make possible the rapid interpretation of video images. We have investigated images arising from a number of areas related to optical fibers and are confident that this technique can be used to advantage in many other studies as well.

REFERENCES

1. H. M. Presby et al., "Rapid Automatic Index Profiling of Whole-Fiber Samples: Part II," B.S.T.J. *58*, (1979) pp. 883–902.
2. D. Marcuse and H. M. Presby, "Automatic Geometric Measurements of Single-Mode and Multimode Optical Fibers," Appl. Opt. *18* (1979) pp. 402–8.
3. P. Snigier, "Graphic Display Devices," Digital Design (April 1980), pp. 39–44.
4. Staff Report, "The Color Impact in Graphic Display," Optical Spectra (April 1980), pp. 46–53.
5. The Video Quantizer used in this work is a Colorado Video, Model 606A.
6. E. G. Rawson, J. W. Goodman, and R. E. Morton, "Experimental and Analytical Study of Model Noise in Optical Fibers," Proc. Sixth Conf. Opt. Commun., York, England, September 1980, pp. 72–5.
7. H. Heaton, "Thermal Straining in a Magnetrostrictive Optical Fiber Interferometer," Appl. Opt. *19* (1980), pp. 3719–20.
8. H. M. Presby and D. Marcuse, "Optical Fiber Preform Diagnostics," Appl. Opt. *18* (1979), pp. 23–30.
9. H. M. Presby and D. Marcuse, "Preform Index Profiling (PIP)," Appl. Opt. *18* (1979), pp. 671–7.

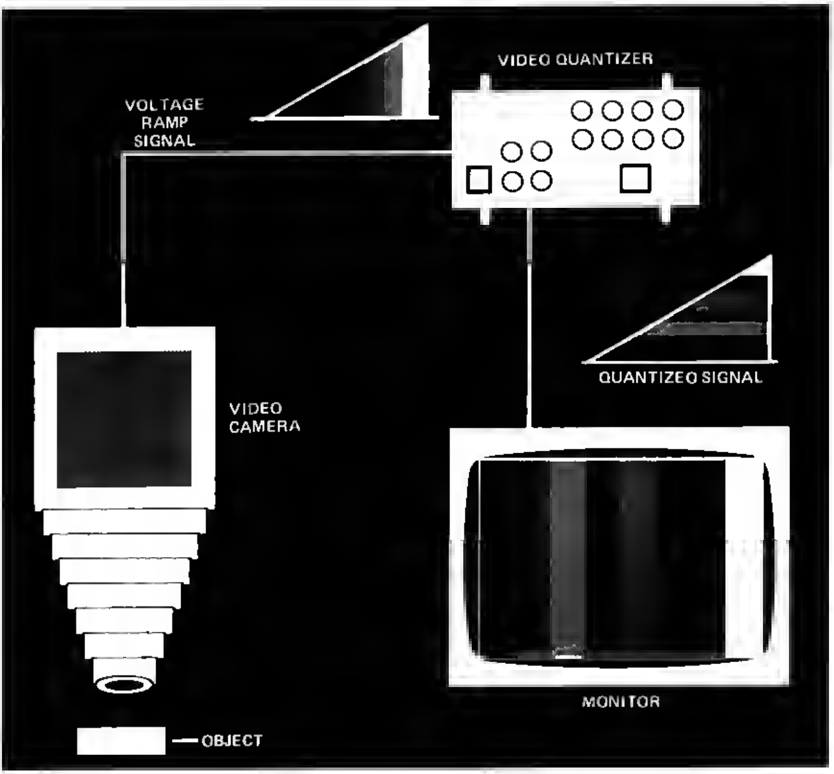

Fig. 1—Arrangement for video colorization diagnostics.

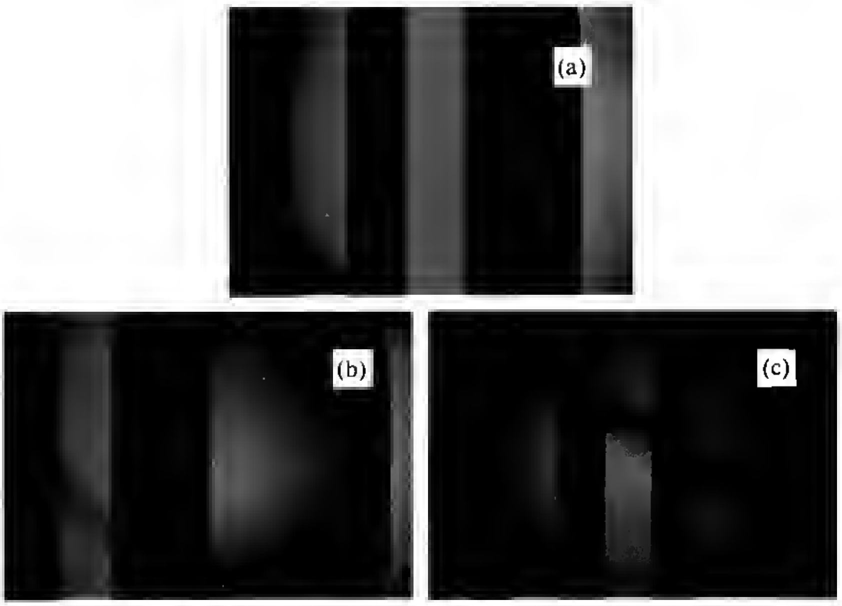

Fig. 2—Test pattern of video quantizer set for (a) bands of equal width; (b) logarithmic response, and (c) equal brightness contour generation.

Fig. 3—Neutral density step wedge observed (a) monochromatically and (b) and (c) by colorization. Note that all eight steps are clearly seen in the latter case.

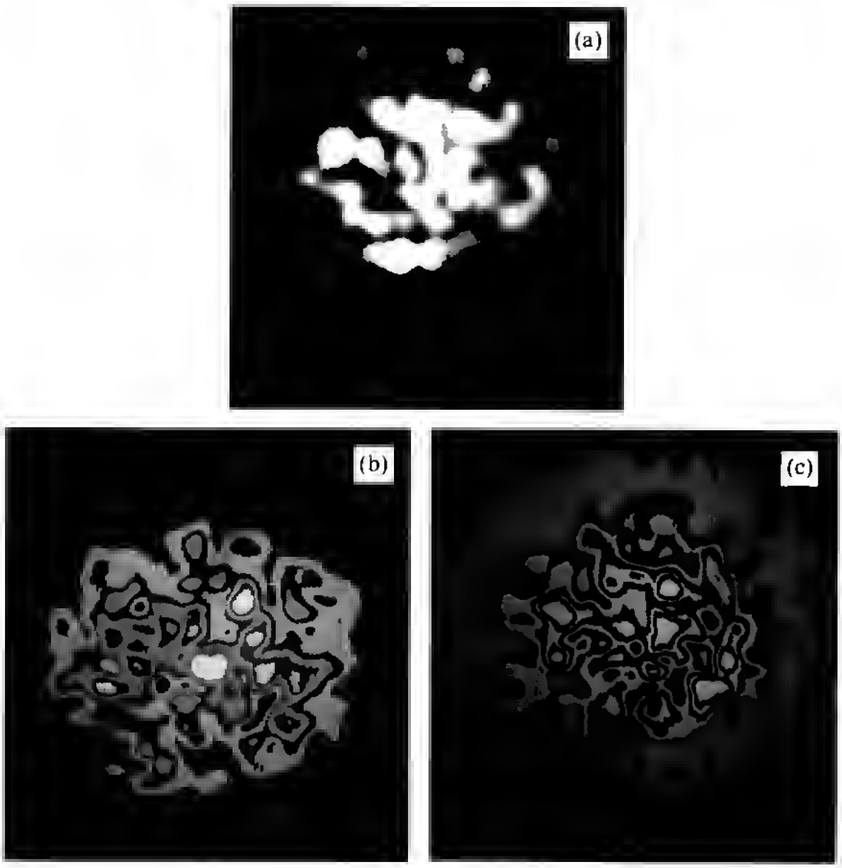

Fig. 4—Output light distribution of multimode optical fiber observed (a) monochromatically, (b) by colorization, and (c) by equal brightness contours.

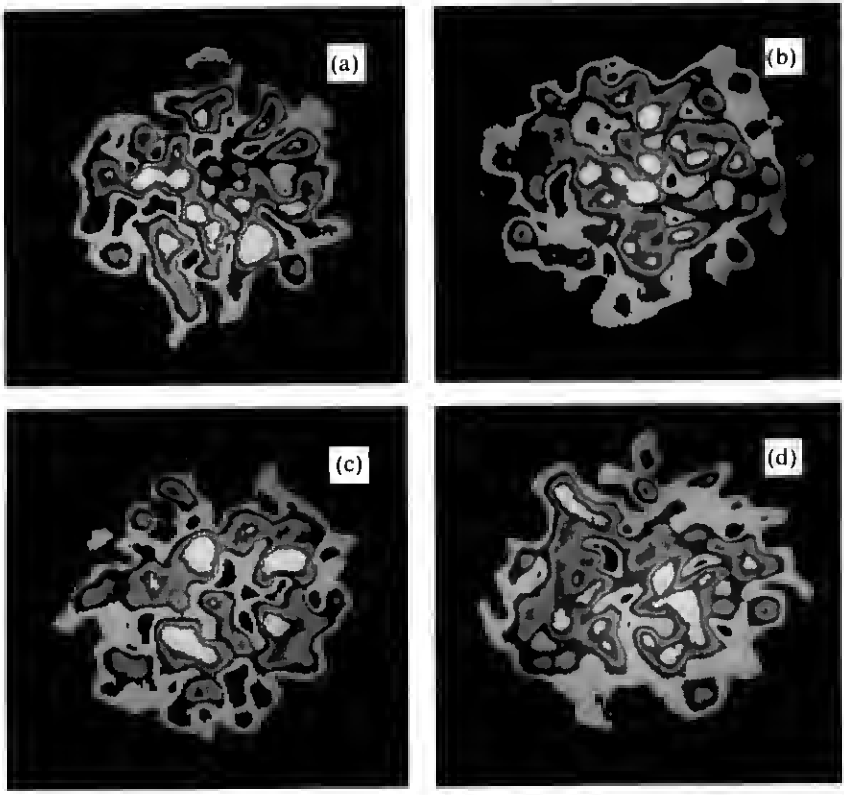

Fig. 5—Variations observed in output light distribution of multimode optical fiber as a function of several minutes' time under ambient room conditions.

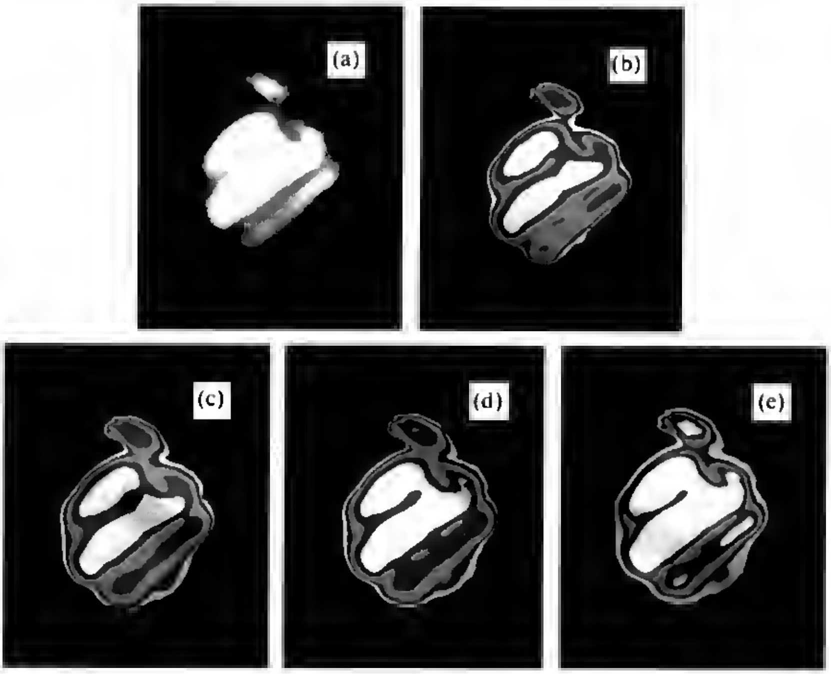

Fig. 6—Near-field light output of poor quality LED observed in black and white and in colorized form as a function of increasing current [(a) through (e)]. Note the changes in the brightest emitting regions shown in white.

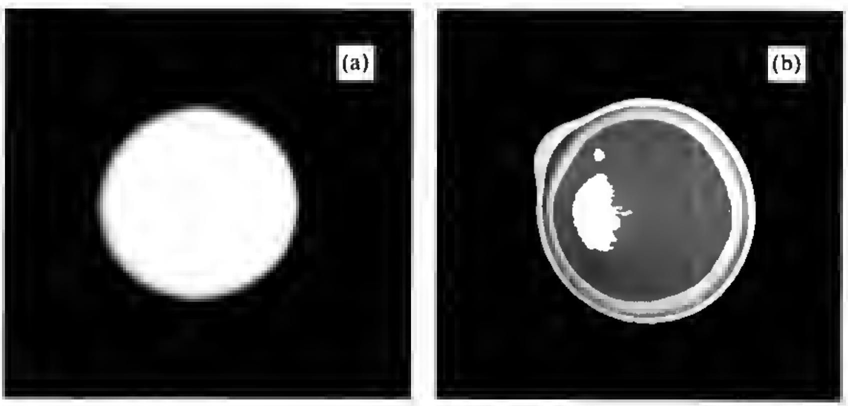

Fig. 7—Light-emitting diode with relatively uniform light output observed in non-colorized and colorized form.

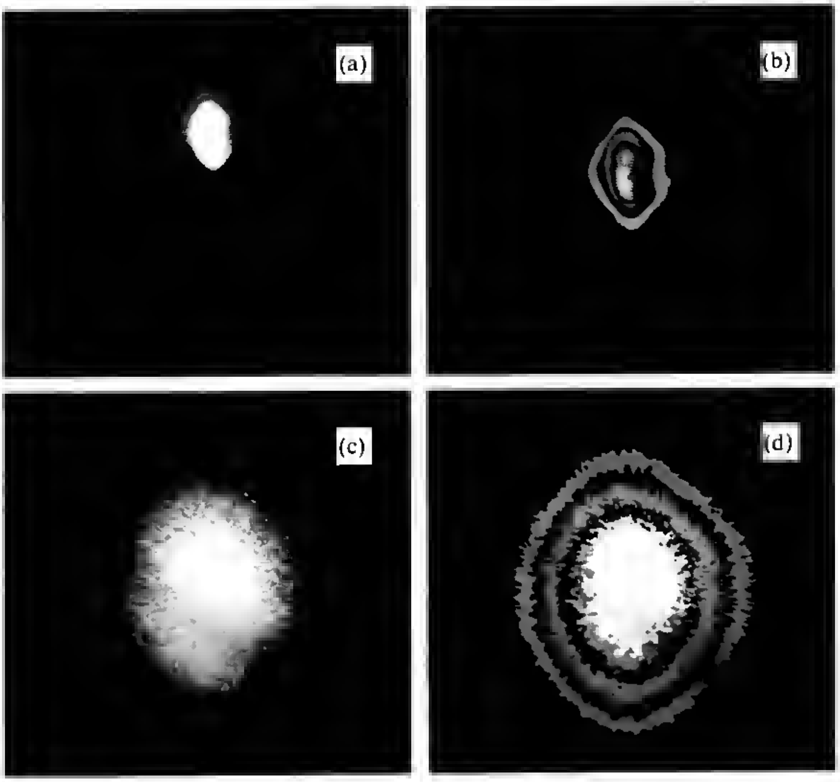

Fig. 8—Near-field [(a) and (b)] and far-field [(c) and (d)] light distribution of GaAlAs laser.

Fig. 9—Multimode optical fiber preform with layer perturbation, observed in (a) black and white and (b) colorization. The colorized form showing how significant process deviations can be readily detected.

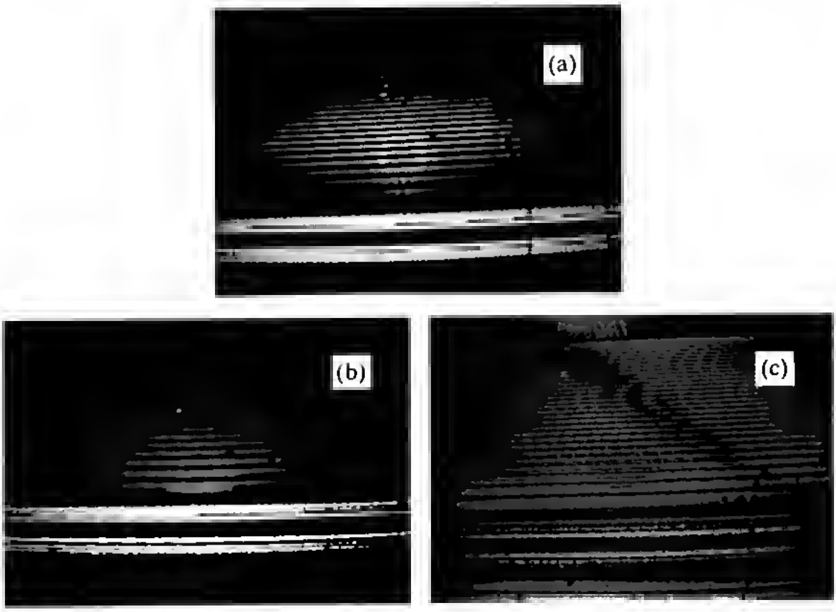

Fig. 10—Observations of single-mode optical fiber preform in (a) monochrome and (b) and (c), colorized form.

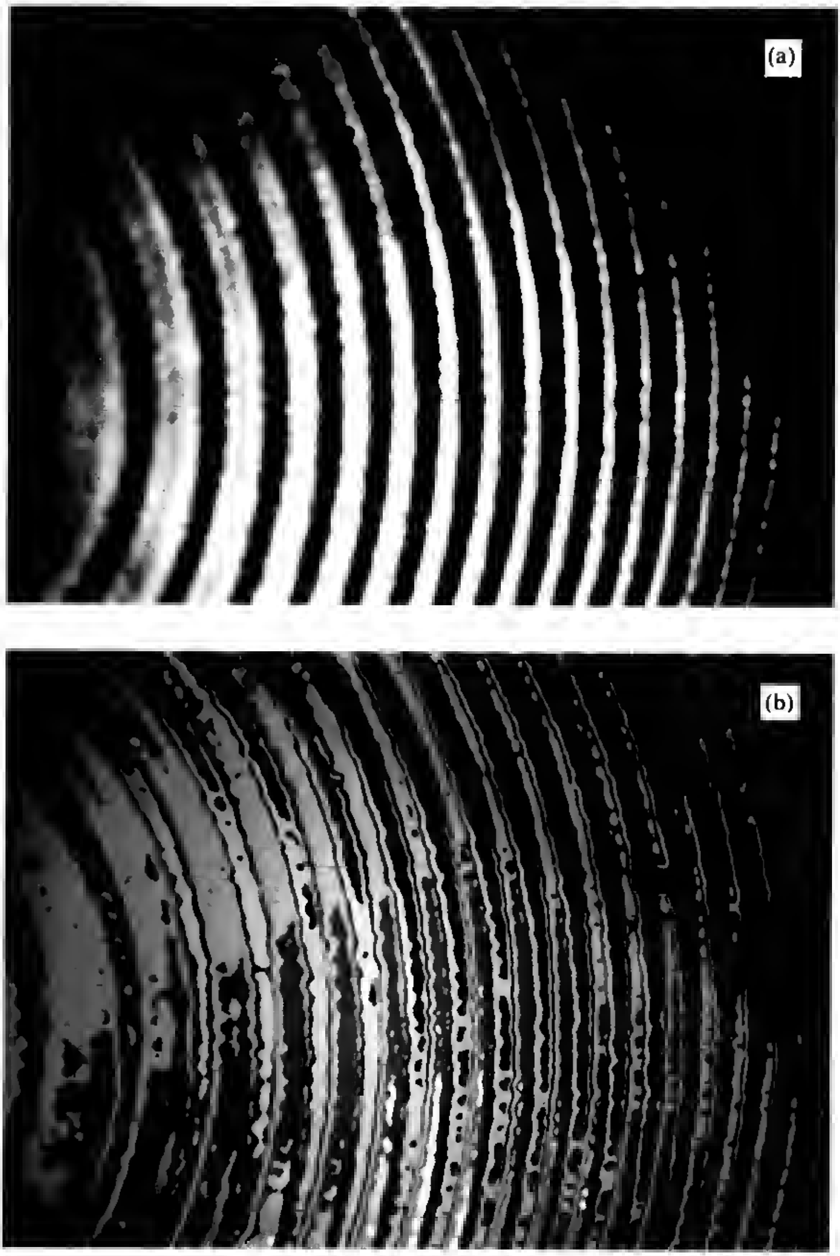

Fig. 11—Slab sample from tip of optical fiber preform showing improved rendering of layer structure achieved with video colorization.

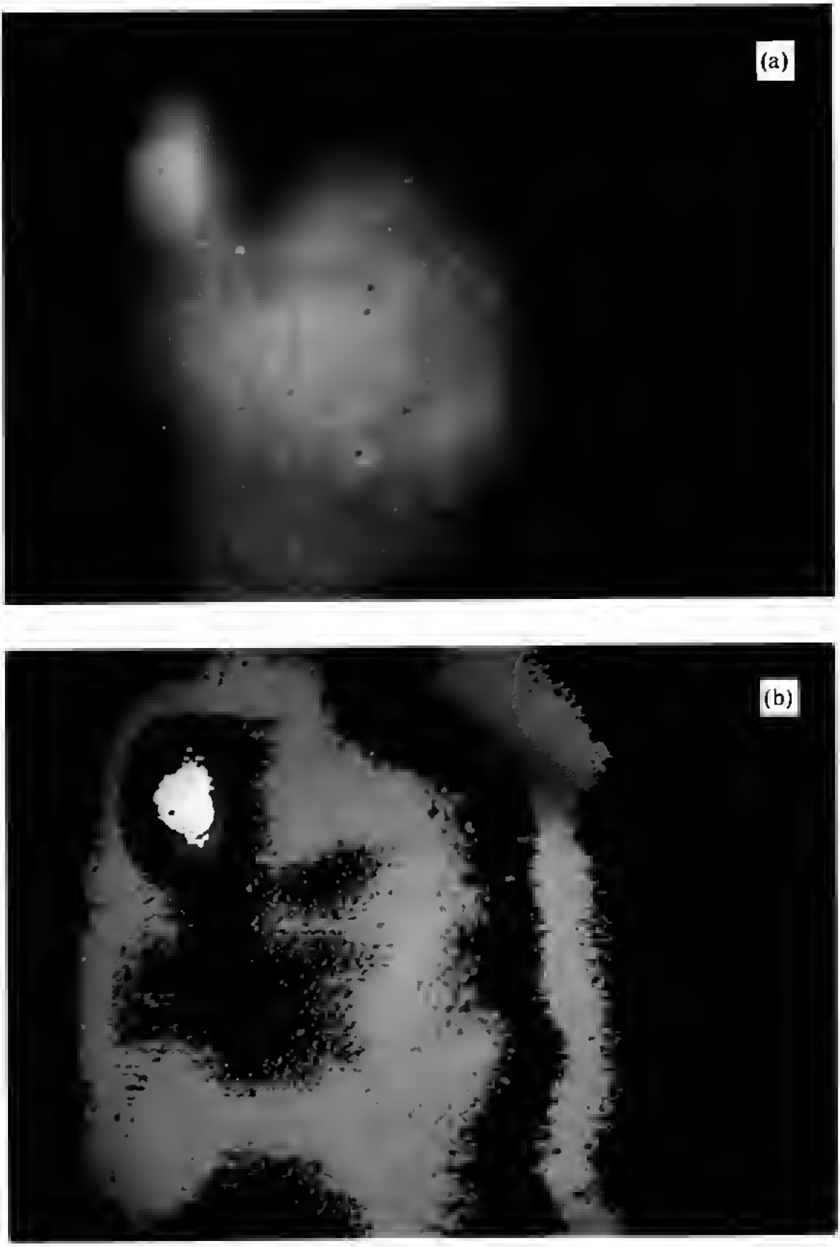

Fig. 12—Light output of tungsten-halogen source showing how nonuniformities are clearly seen with video colorization.